SRF2007

Superconducting RF photoinjectors; an Overview

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General Remarks

Motivation

The main motivation for the SRF-photoinjectors is to enable high duty factor (cw) operation of superconducting accelerators driving the FEL and ERL facilities.

Other applications:

- **Electron cooling**
- **Electron-ion colliders**
- ***Polarized electron source for ILC (more Ilan Ben-Zvi on Friday)***

R&D at laboratories and Universities:
BNL, Peking University, MIT, JLab, BESSY, FZR, Daresbury, DESY…

General Remarks

The goal is: generation of low emittance electron beams in the cw mode.

The beam parameters range is rather broad:

q/bunch	77 pC -> 2.5 nC
ε_n	1 μm·rad -> 3.6 μm·rad
I_b	25 μA -> 0.5 A

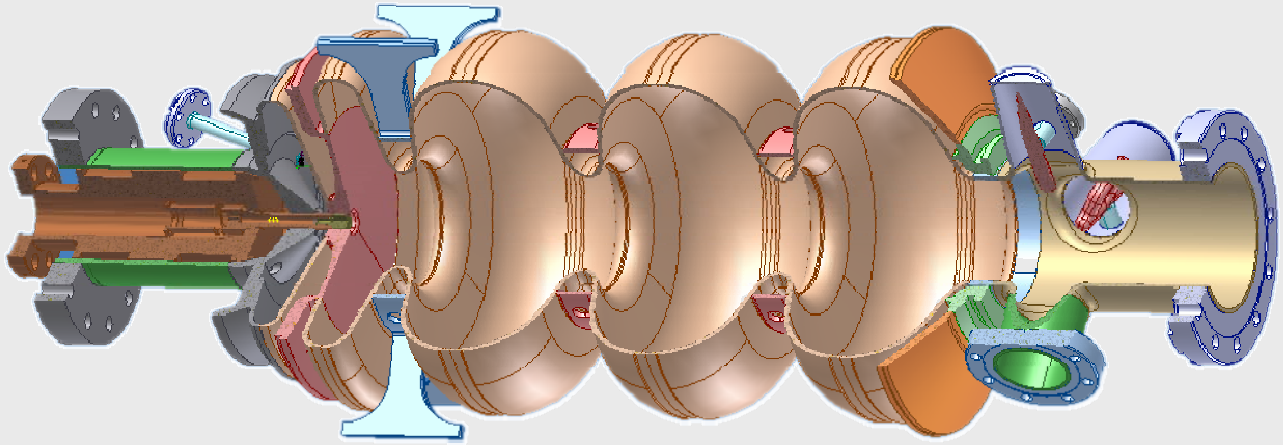
In general, there are three technically different approaches:

	Cathode and Cavity	Main advantage	Main disadvantage
I	NC cathode + SRF cavity	High QE	Integration of the cathode in the SC environment
II	NC cathode in DC gun + SRF booster cavity	High QE	Larger emittance
III	SC cathode + SRF cavity	Simpler integration of the cathode in the SC cavity	Low -> moderate QE

I. NC cathode + SRF cavity

FZ Rossendorf / BESSY / DESY / MBI Collaboration (the most advanced project)

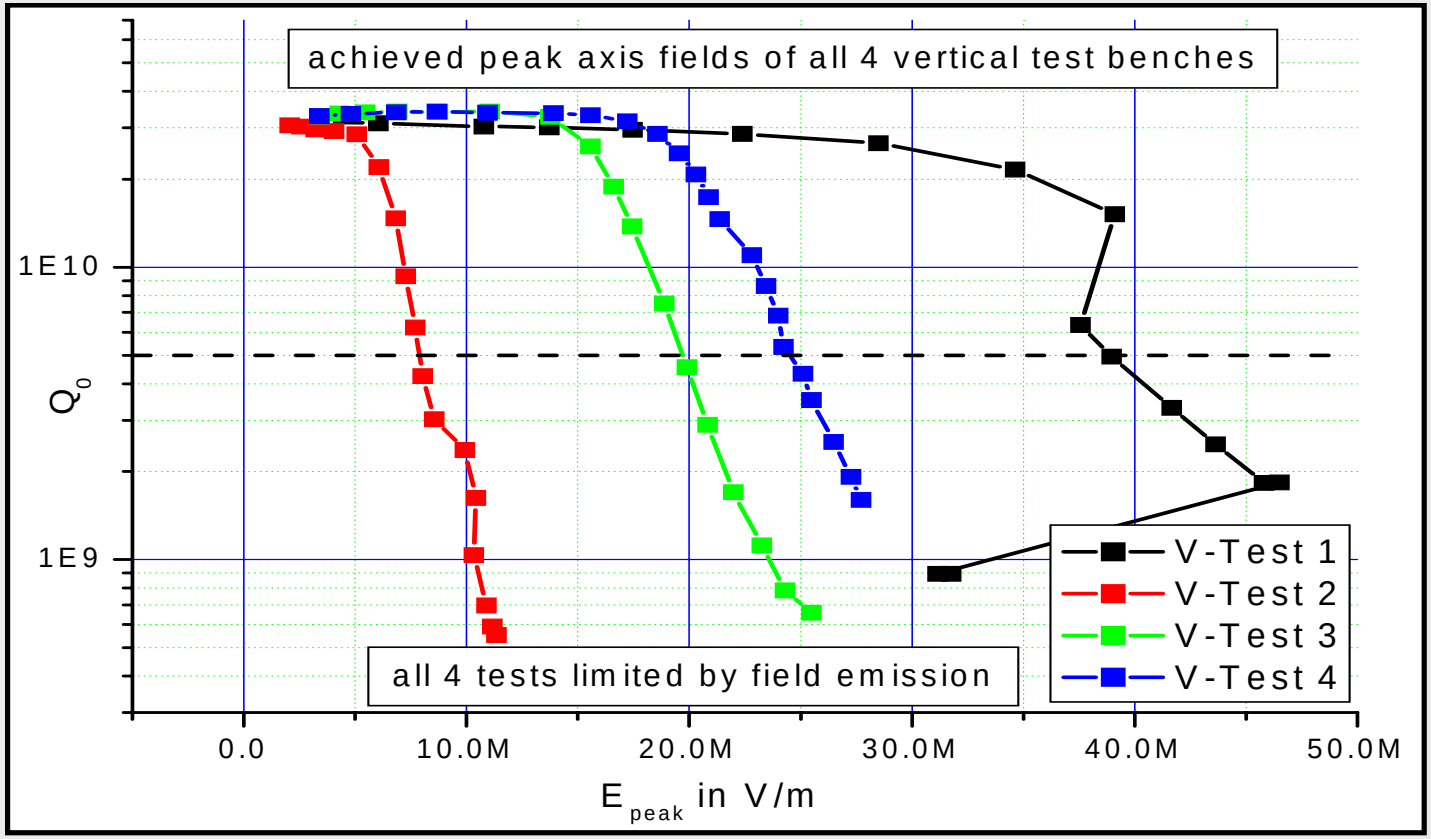
Cavity: bulk polycrystalline niobium @ 3 ½ cell+ choke filter @ 1.3 GHz



Parameter list for three operation modes of the FZR photoinjector

	ELBE mode	High charge mode	BESSY-FEL
E_b	9.5 MeV		
operation	CW		
λ	262 nm		
Photocathode	Cs_2Te		
QE	>1 %		>2.5 %
I_b	1 mA	0.5 mA	2.5 μA
Pulse length	5 ps	15 ps	40 ps
Repetition rate	13 MHz	500 kHz	1 kHz
q/charge	77 pC	1 nC	2.5 nC
ε_n	1 μmrad	2.5 μmrad	3 μmrad

Cold tests at DESY in 2006/2007:



Values @ Q_0=5x10^9	1st BCP / HPR @DESY	2nd HPR @ DESY (Crash)	3rd BCP / HPR @ ACCEL	4th BCP / HPR @ ACCEL (crash)
E_{acc}	14.6 MV/m	2.8 MV/m	7.4 MV/m	9.3 MV/m
E_{peak}	39.0 MV/m	7.4 MV/m	19.6 MV/m	24.6 MV/m
P_{diss}	32 W	1 W	8 W	13 W

I. NC cathode + SRF cavity

Beam test at FZR in preparation:

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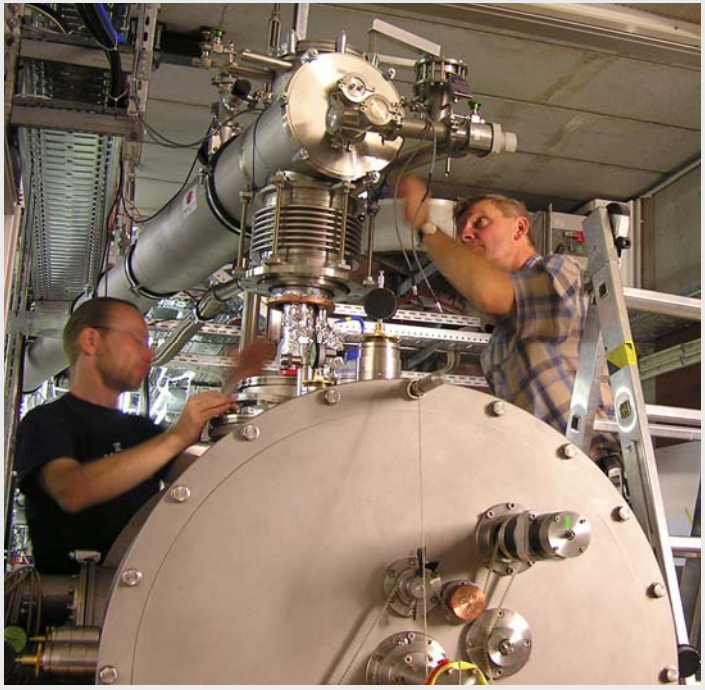
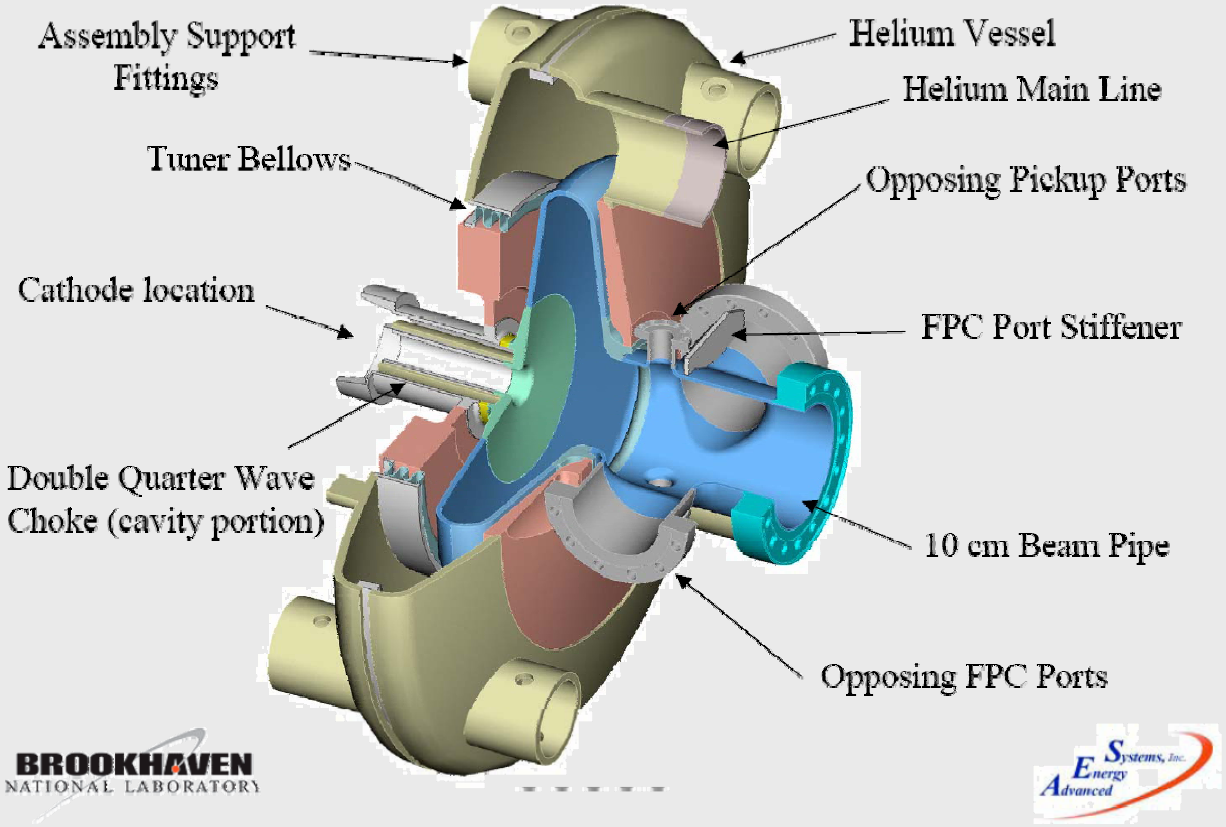
- **Finishing the installation of the gun in July 07**
- **Cool-down and commissioning took place in August 07**
- **Installation of the laser (500 kHz system) was in August 07**
- **Test with Cu cathode will be performed in October/November 07**
- **Installation of cathode transfer system and diagnostics beamline in October 07**

Cavity prepared for final assembly



Ampere-class SRF gun. Collaboration BNL / AES



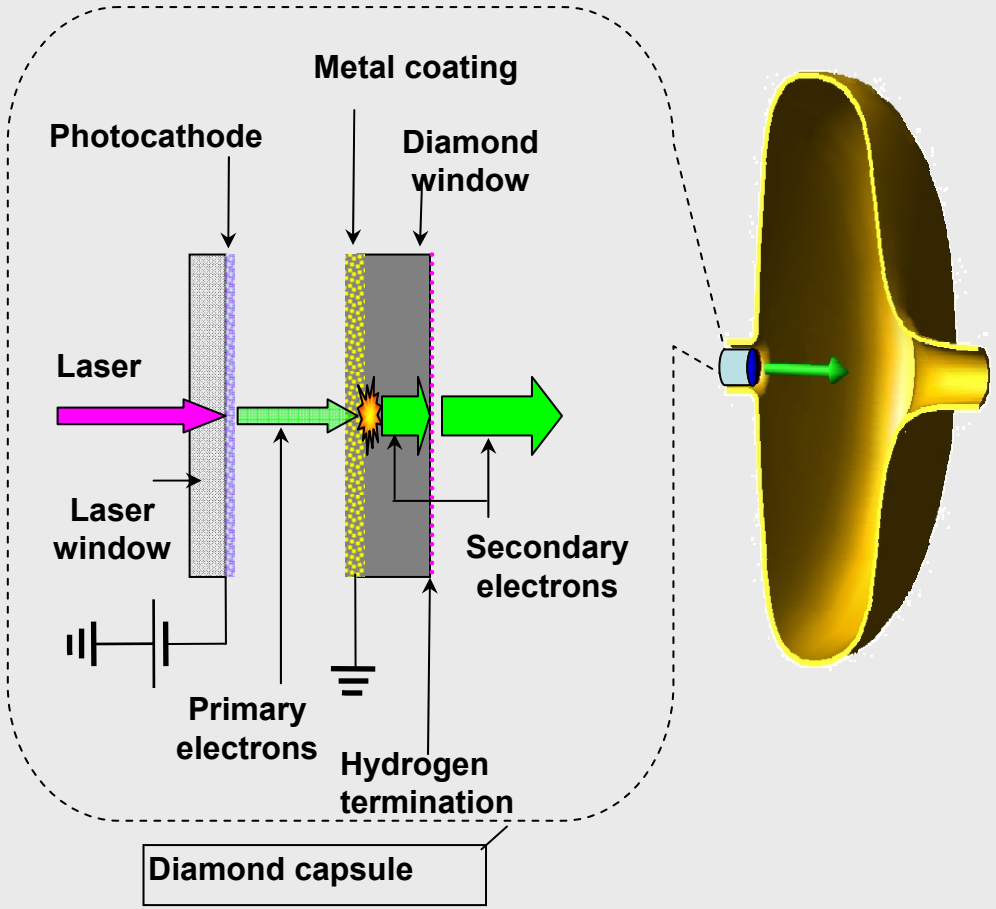
Cavity: bulk polycrystalline niobium, ½ cell (1.5)

Parameter list for the first and second stage of the BNL/AES photoinjector

	0.5-cell	1.5-cell
Frequency	0.70375 GHz	0.70375 GHz
q/bunch	1.4 nC	5 nC
ε_n	2 μrad	3 μrad
Energy	2-3 MeV	5 MeV
P_b	1 MW	-
I_b	0.5 A / 1A (0.1A)	-
Rep. rate	352 and 704 MHz (9.4 MHz)	-
Cathode	CsK_2Sb	
QE / QE with Diamond	1% / >100%	-
Laser λ	532 nm	-

I. NC cathode + SRF cavity

Diamond e-multiplier:



- **High gain (secondary current / primary current), over 350 demonstrated**
- **Low thermal emittance**
- **Absolute separation of gun and cathode.**

II. NC cathode in DC gun + SRF booster cavity

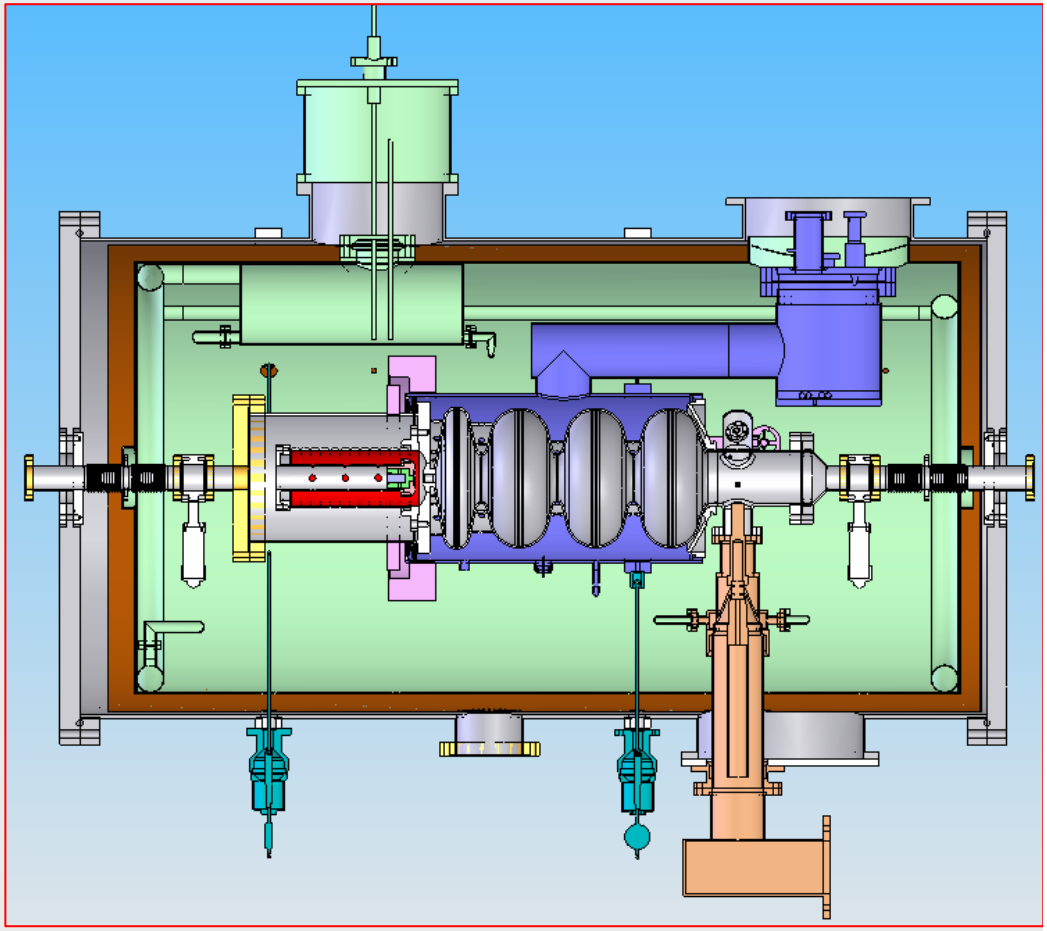
Proof of principle in 2004 for the concept

Beam test in 2004 with ½-cell

	Unit	Spec (2K)	Test (@4.2K)
Eacc	MV/m	15	6
E	[MeV]	2.6	0.5 (max 1.1)
I_b	[mA]	1-5	0.27
q	[pC]	60	3
ΔE (rms)	keV	30	35 @ 500 keV 70 @ 1 MeV
rms ε_n	[μrad]	3 @ 60pC	5.4 @ 3pC 2.8 @ 1pC
f rep.	[MHz]	81.25	81.25
DC	[kV]	100	40

DC-SC photoinjector at Peking University

Frequency	1.3 GHz
E at cathode	6 MV/m
V_{DC}	90 kV
q/bunch	100 pC
Energy	5 MeV
E spread	0.64%
rms ε_n	3.6 mm-mrad @ 5 MeV
I_b	1~5 mA
Rep. rate	Up to 26 MHz
Cathode/ QE	Cs_2Te, 1~5%
Laser λ	266 nm



II. NC cathode in DC gun + SC booster cavity

3+1/2 cell DC-SC photoinjector

- **Large grain niobium is used for fabrication of 3+1/2 cell SRF cavity**
- **Design is finished, cavity and cryostat are in fabrication**
- **It will be implemented in the IR FEL facility at Peking University**

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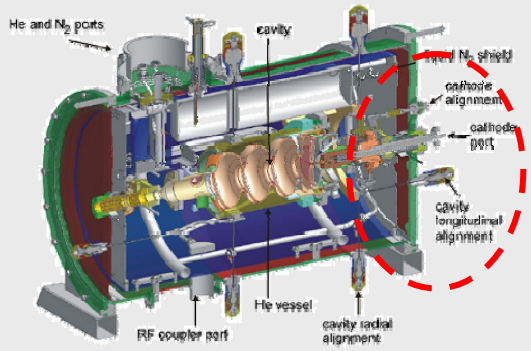
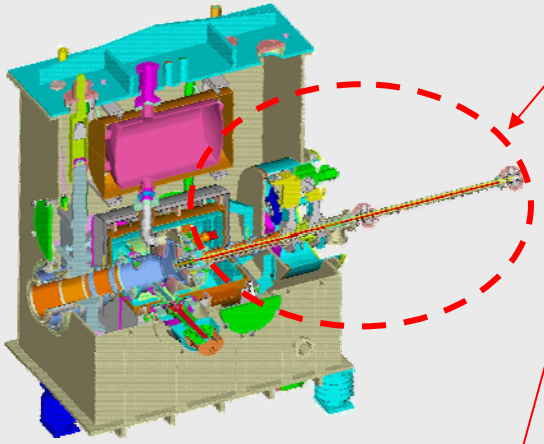
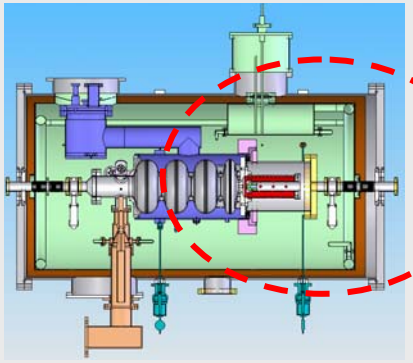
III. SC cathode + SRF cavity







The main difficulty in all three approaches is integration of a non-superconducting cathode, having limited lifetime, in the sc cavity:

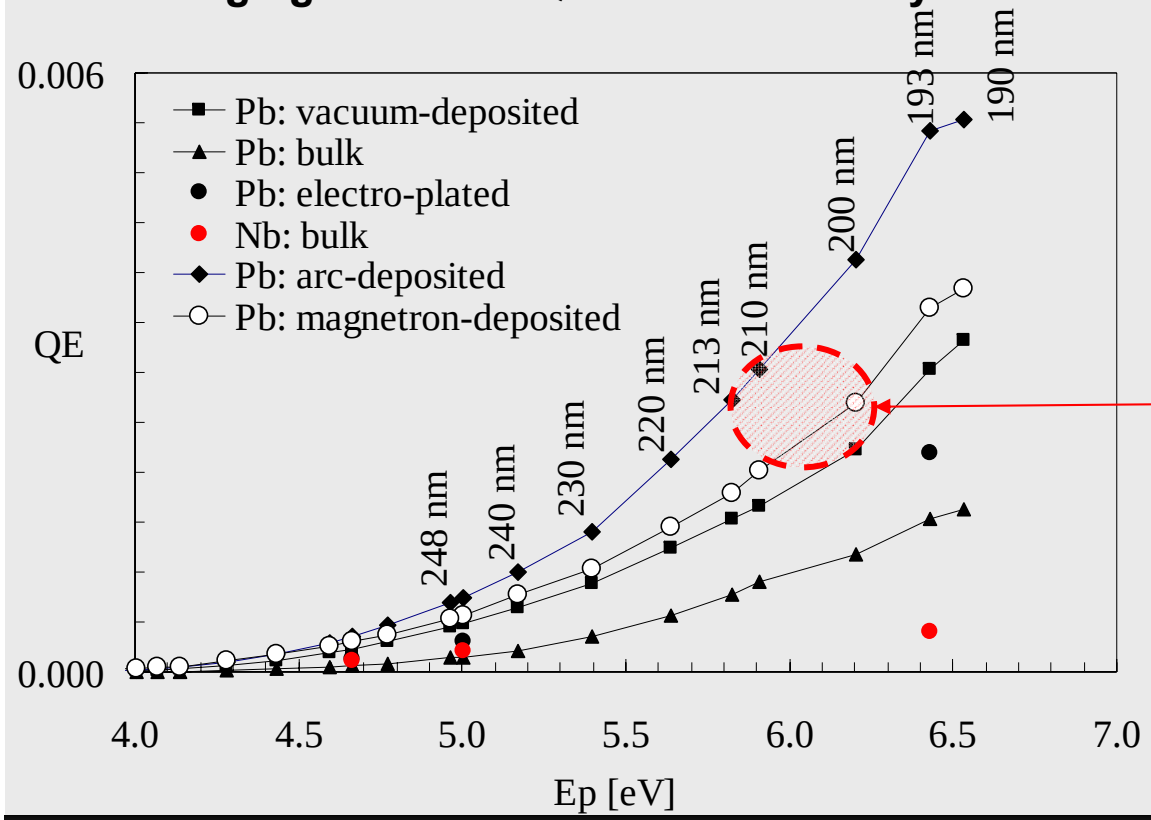
1. **Very complicated mechanism for cathode exchange**
2. **Potential contamination of the sc surface (FZR, PKU)**
3. **Multipacting in choke filters**
4. **Field nonlinearities in the vicinity of the cathode**

Bulk Nb cavity with Pb emitting spot

Bulk 1.5-cell niobium cavity with arc deposited emitting spot of lead, which is commonly used superconductor (Tc=7.2 K):

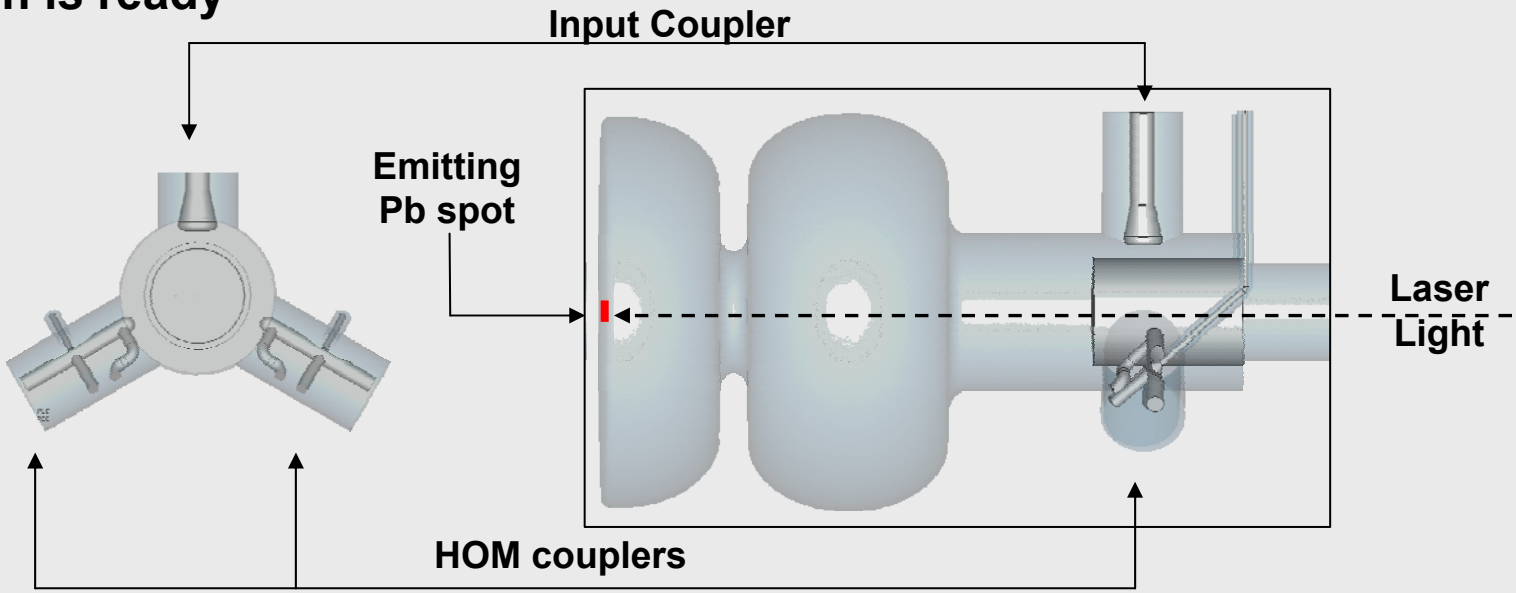
- **Use of superconducting photo-cathode simplifies construction of the injector.**
- **In addition the metallic cathode should have very long life time.**

Encouraging results of Quantum Efficiency tests



QE sufficient to generate ~1 nC at rep. rate ≤1MHz

RF-design is ready

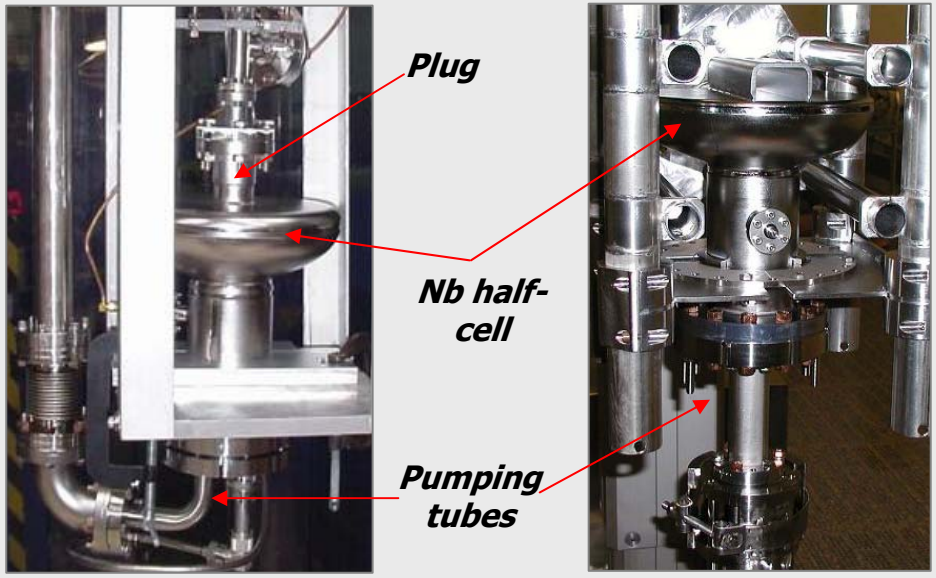


Parameter	Unit	Value
π -mode frequency	[MHz]	1300
Cell-to-cell coupling	-	0.015
Active length 1.6· λ /2	[m]	0.185
Nominal E_{cath} at cathode	[MV/m]	60
Energy stored at nominal E_{cath}	[J]	20
Nominal beam energy	[MeV]	6

RF-PERFORMANCE TEST

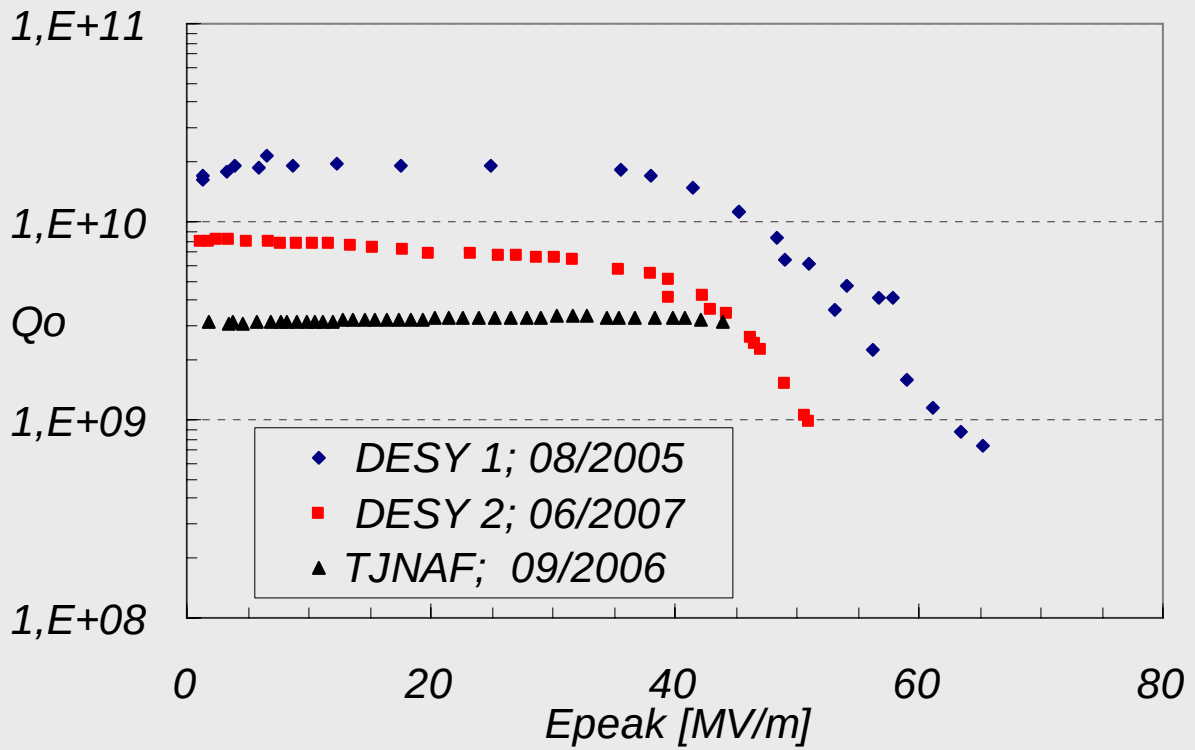
Two types of half-cell resonators have been built to measure the QE of lead at 2 K and to test the RF performance of the Nb-Pb cavities

Cavity built at TJNAF
It has an opening in the center of the back wall, which is vacuum sealed with a niobium plug and an indium gasket.



Cavity built at DESY
In this cavity, the technically difficult coating is done directly on the back wall. An additional difficulty in this version is that the emitting spot must withstand cleaning procedures applied to the cavity.

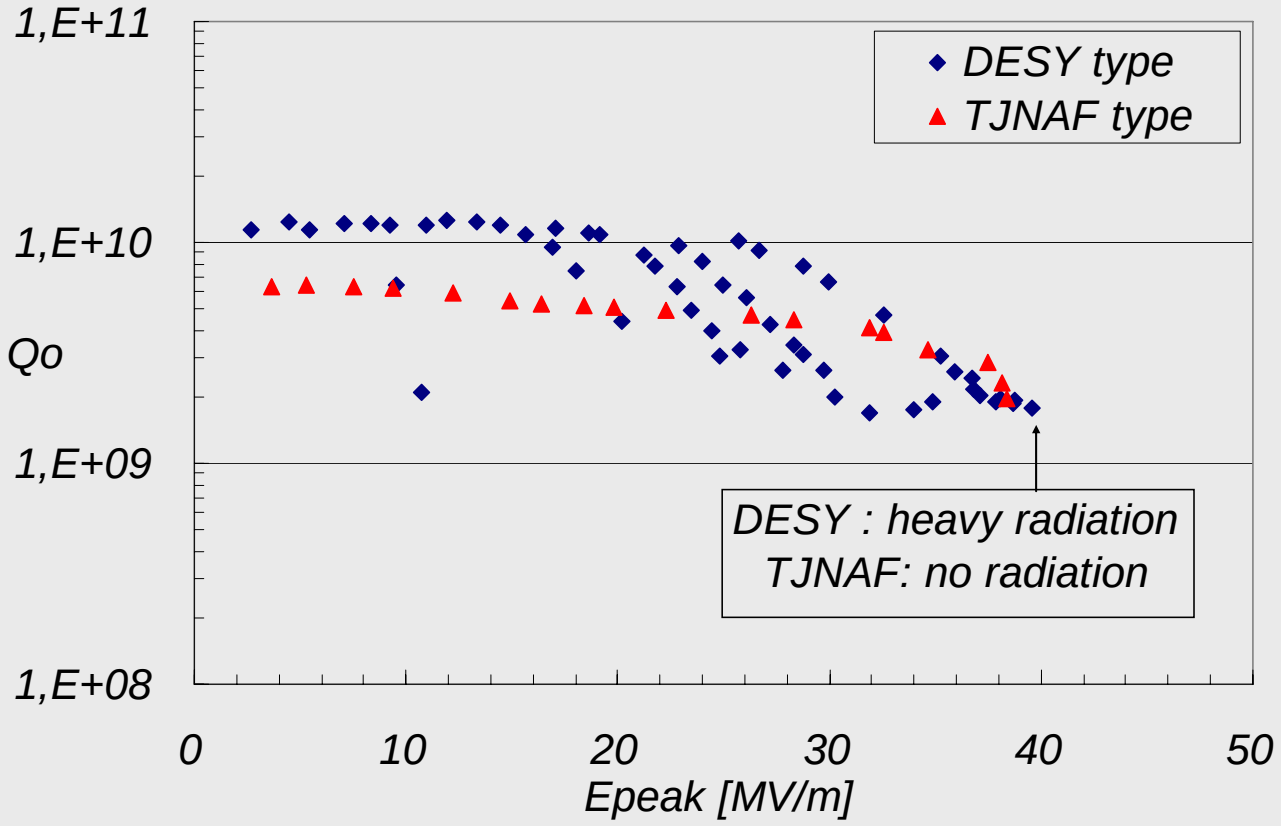
RF-PERFORMANCE TEST without the Pb spot.



RF-PERFORMANCE TEST with the Pb spots.

The emitting 4 mm diameter lead spot at the center of the back wall of the DESY cavity was deposited by the arc-discharge method at A. Soltan INS.

The 7 mm diameter plug of the TJNAF cavity was electroplated with lead at Stony Brook University.



III. SC cathode + SRF cavity

RF-PERFORMANCE TEST, cont.

To produce an average current of 1 mA (1 nC@1MHz), we need ~3 W at 213 nm

3μJ/pulse (20ps) @ 1μJ/mm^2

1) The sc surface of the DESY cavity was exposed to 0.75 W power of excimer (KrF) laser:

2.9 mJ/pulse (5 ns, spot size 20 mm^2) @ 250 Hz @ 150μJ/mm^2
was insufficient to cause quench !!!
We observed only Qo reduction by 20 %

2) QE measured at 300K was confirmed at 4K

Next steps:

- **Coating of additional plugs with Pb and tests with the TJNAF cavity**
- **RF test of the second DESY structure with Pb spot**
- **Improvement in the coating technique (arc-deposition)**
- **Fabrication of 1.5-cell structure and tests with and without Pb spot**

III. SC cathode + SRF cavity

Pb-Nb Collaboration

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